Rotating blades, which are the most critical components of any turbo-machinery, need to be designed to withstand forced vibrations due to accidental tip rub impact against inner surface of casing. These vibrations are typically dependent on operating conditions and geometric parameters. In the current study, a rotor test rig with a maximum tip speed capability of 144 km/hr has been developed for studying the dynamic behavior of representative jet engine compressor blades actuated by the closure of clearance between the tip of a given rotating blade and a sector of the inner lining of the casing. Ten different blade profiles are chosen in the present research. The blades are obtained by lofting NACA GOE123 airfoil cross-section along different stacking axes.

Rotor test rigs which simulate transient dynamic events require high frequency data acquisition systems like slip ring arrangement or telemetric transmission. While slip rings introduce noise into the signal, the telemetric transmission works out to be rather expensive. To circumvent the stated shortcomings of data acquisition systems, a novel rotor-mounted data acquisition system has been implemented here which captures dynamic strains in vibrating blades during operation. The current data acquisition system can store data for duration of five seconds with a sampling rate of 35 kHz. It has been calibrated with four standard tests, and provides a simple and efficient mode of data capturing. Three blades with airfoil sections (a flat beam-type blade of uniform rectangular cross-section, a blade with twisted cross-sections stacked along a straight line, and a blade similar to the latter but with a curved stacking axis) are tested under controlled rub conditions at four different speeds. The maximum test speed is restricted to 800 rpm for reasons of safety although the set-up is designed to operate up to a maximum speed of 2000 rpm. For each of the rotor speeds, a blade is tested for three to four different stagger angles in the range of 0^{o}-30^{o}. By plotting the RMS values of measured dynamic responses with respect to stagger angle for a given rotor speed, it has been observed, perhaps for the first time in published literature, that a stagger angle of around 20^{o} yields the maximum RMS value of strain response.

A major objective of the current study has been to utilize the data generated in the tip rub impact tests for validating a predictive numerical model of the test set-up using explicit finite element analysis. To this end, a finite element model of the rotor rig inclusive of a rotor with two blades and the static frame structure is developed and analyzed using an explicit LS-DYNA solver. This model is calibrated with the test results of the three blade designs described above. In particular, it has been shown that the frequency contents of the measured dynamic strain responses agree quite well with frequencies obtained from the numerically computed responses. It has been found in the experimental responses that a given blade vibrates with two main frequencies: one corresponding to the first natural frequency of the rotor-blade system during the tip-rubbing phase (which lasts until the blade tip is in contact with the rub element which is a sector of the circular casing), and another corresponding to the first natural frequency of the blade when it vibrates freely without its tip being in contact with the rub-liner of the casing. A shortcoming of the current modeling approach is its inability to realistically represent the damping behaviors observed in the tests. For reasons of computational efficiency and consistent with the fact that there was no perceptible damage in the tested blades, an elastic constitutive behavior is specified for the blades, while the sacrificial PVC rub-liner is assumed to behave elasto-plastically. A limited study has also been carried out by assigning an elasto-plastic constitutive model to one of the blades previously represented with elastic properties only, and although incipient yielding is observed in a highly localized region at the tip of a blade (which can also be a numerical artifact), the responses under the two material behavior considerations (i.e. elastic and elasto-plastic) are found to be nearly same.

Finally, this validated modeling approach is applied to the study of blades of ten distinct geometric profiles (including the three configurations already considered) at a speed of 800 rpm and the resonant speed of a given blade. Comparisons are made between the relevant responses (such as time-histories of root strain, shaft torque, blade axial displacement, bearing load and rub force) of nine blades with airfoil cross-sections (leaving aside the results for the first blade of rectangular cross-section which is only of academic interest). Based on this study, of all the blade designs, it has been found that the curve-stacked airfoils exhibit better ‘Rub-tolerant’ behavior. Both experimental and simulation results have predominantly proven the fact that adding curvature to a straight stacked blade through curve-stacked or bow result in reducing the rub induced vibration. While sweep and bow provide some aerodynamic advantages, they are not much helpful in containing the vibrations to a sustainable extent.